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# Energy Gaining Windows for Residential Buildings

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*KEYWORDS: Low- energy windows, slim frame profiles, solar gain, net energy gain, low energy houses*

*SUMMARY:*

*This paper presents some of the research done during the last 8 years at the Technical University of Denmark developing improved low-energy window solutions. The focus has been on maximizing the net energy gain of windows for residential buildings. The net energy gain of windows is the solar gain minus the heat loss integrated over the heating season. It is assumed that in northern cold climates all of the solar gain during the heating season can be utilized for space heating. Problems with overheating in the summer period must be solved with overhang or moveable solar shading devices.*
*Two windows have already been developed and prototypes constructed for laboratory test and a third generation of the window design is now in the developing and designing phase in a new project.*
*The first window constructed was made of wood profiles and a low-energy double glazing unit. The second and third windows are made of fiber-reinforced plastic (plastic reinforced by fine fibers made of glass). This composite material is a weatherproof material with very low thermal conductivity and high mechanical strength. These properties make the material very suitable for frame profiles due to lower heat loss and longer durability of the window. The glazing in these fiber reinforced polyester windows is both unsealed and sealed triple glazing units.*
*To increase the net energy gain slim frame profiles have been developed to increase the glazing area and thereby the solar gain. The challenge when developing slim frame profiles is to make enough space for hinges and fasteners and still maintaining the functionality and strength of the window. Proposals for new hinges and handles are also given in this paper.*

## 1. Introduction

The energy consumption for the space heating of buildings was in 2007 about 40 % of Denmark's total energy consumption, of which approximately 25 % are assumed to be heat loss through windows. There is therefore a considerably energy saving potential in developing new and better low-energy windows both for use in renovation of the existing building mass and for use in new buildings. The EU Directive on Energy Performance of Buildings (EU Directive, 2002) was implemented in Denmark in 2006, and in order to comply with the directive, Denmark introduced new energy performance requirements in 2005 (Danish Building Regulations, 2005). The key to fulfill these new requirements is often the selection of the best available window components. On the Danish window market only a few products have been developed during the last couple of years and there is therefore a great need to help the entire window line to start this developing process. The development of improved frame constructions has not kept up with the development in the glazing area. Therefore, windows are not nearly as good as the glazing in these.

One of the main objects of the research done during the last 8 years at The Technical University of Denmark has been to form the basis of the development of Danish windows with a positive net energy gain to the house still maintaining a long lifetime and an architectural attractive form. The general goal of the project is to make the window an energy gaining component of a house and not as today an energy consuming component.

This development will support both the present and the future (2010 and 2015) tightened energy requirements in the building regulations.

The window designs presented in this paper differ from the traditional high insulated passive house windows by focusing on the energy balance of the window. By using slim frames, the solar radiation through the glazing is maximized, which is an advantage in cold climates where all the solar radiation can be utilized for space heating in the heating season. To avoid overheating problems during the summer, large overhangs from the roof or solar shading devices are probably necessary, especially in low-energy houses.

## 1.1 Definition of the Net Energy Gain

It is difficult to evaluate the performance of a window based on the heat loss coefficient (U-value) and the solar energy transmittance ($g_w$) separately. It is therefore obvious to use the Net Energy Gain illustrated in figure 1 as this value takes into account both the $U_w$-value and $g_w$-value (Nielsen, T. R. et al, 2000). The net energy gain is defined in eq. (1) and fitted for the Danish climate based on the test reference year (DRY) in eq. (3). The $g_w$-value of the window is defined in eq. (2).

Net Energy Gain = Solar Gain – Heat loss

$$NEG = g_w \cdot I - U_w \cdot G, \quad \text{where} \qquad [\text{kWh/m}^2] \qquad (1)$$

$$g_w = g_g \cdot \frac{A_g}{A_w} \qquad [-] \qquad (2)$$

$g_w$ solar energy transmittance of the window
I total solar radiation in the heating season
$U_w$ heat transfer coefficient (U-value)
G degree hours

The expression of the net energy gain for the Danish climate is based on the period from 24/9 to 13/5 (heating season) and the following distribution of the windows in a house:

South: 41% , North: 26%, East/West: 33%

A shadow factor of 0.7 is used for the corrections for the effects of shadows. The net energy gain for Danish conditions is given as (Nielsen, T. R. et al, 2000):

$$NEG_{DK} = g_w \cdot 196.4 - U_w \cdot 90.36 \qquad [\text{kWh/m}^2] \qquad (3)$$

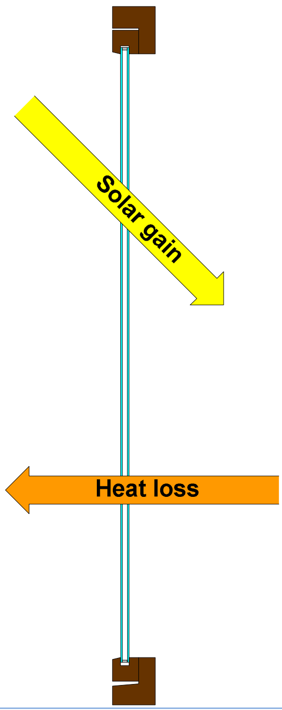



*FIG. 1 Definition of the net energy gain of a window in a reference house in Denmark.*

Other definition assumed in this paper:

- Standard size of a window is defined as 1230 x 1480 mm
- The type of the window is a single-light (window without mullions, transom or glazing bars)
- Frame width: The visible projected width of the frame section (seen from the front)

## 1.2 Previously developed frame profiles at DTU

Two windows were developed in previously finished project at The Technical University of Denmark. Both windows were designed with slim frame profiles produced in the projects “Projekt Vindue“ and “Energirigtige vinduessystemer“ financed by the Danish Energy Authority and VILLUM KANN RASMUSSEN FONDEN, respectively. The profile designs and pictures of the prototypes are presented in figures 2 and 3.

**The first window**

The first window was constructed with frame profiles made of wood and covered with aluminium. The used glazing was a double layer low-energy glazing 4-15-4 mm with 90/10% argon filling in the gap and a low-emittance coating on the inner pane on the surface facing the gap. To get a high g-value the outer pane was made of float glass with low iron content. Moving the sash out in front of the outer frame reduces its width to approximately 5 cm. Hereby the glazing area is increased by 15% (for the standard window dimensions: 1480 x 1230 mm) compared to a corresponding window of wood with a frame width of 10 cm.

In the bottom between the aluminium and the wood a weather strip of flexible elastomeric foam is mounted to prevent ventilation of the cavity between the aluminium and the wood. (Laustsen, J. B et al, 2005).

**The performance of this window is:**

$U_f = 1.33$ W/m²K

$U_w = 1.23$ W/m²K

$g_w = 0.57$

**$NEG_{DK}$ = -3 kWh/m²**

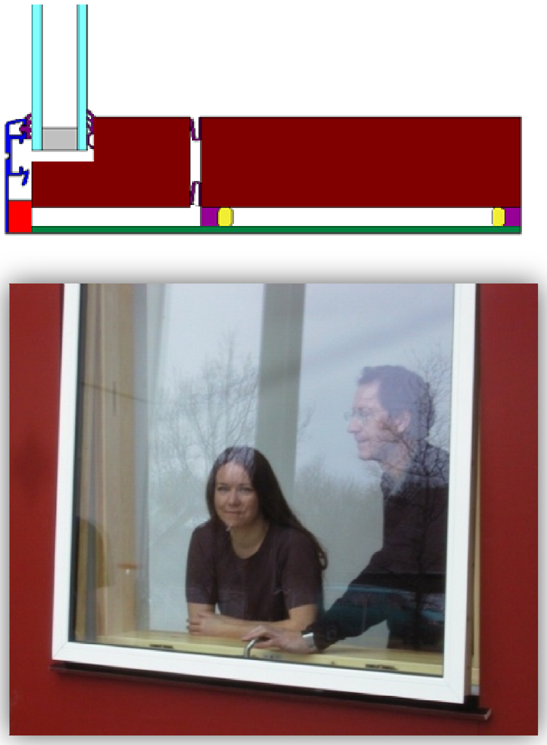


*FIG. 2 The first prototype constructed at DTU*

**The second window**

The frame was made of fibre glass reinforced polyester, which is a weatherproof material that in combination with a non-sealed glazing unit with two hard low-emittance coatings results in a considerably better durability than traditional windows.
It has often been asserted that the hard low-emittance coating can distort the colour reproduction more than the soft low-emittance coating and thus give a poorer daylight quality in the room. A questionnaire investigation was carried out, in which 36 test persons were asked to estimate the daylight conditions in four identical offices with different glazing solutions. The investigation showed, among other things, that no marked difference was observed in the daylight quality of rooms with a triple-glazing with soft or hard low-emittance coatings. It could therefore be justified to use the hard low-emittance.

**The performance of this window is:**

$U_f = 1.40$ W/m²K

$U_w = 1.03$ W/m²K

$g_w = 0.54$

**$NEG_{DK}$ = 13 kWh/m²**

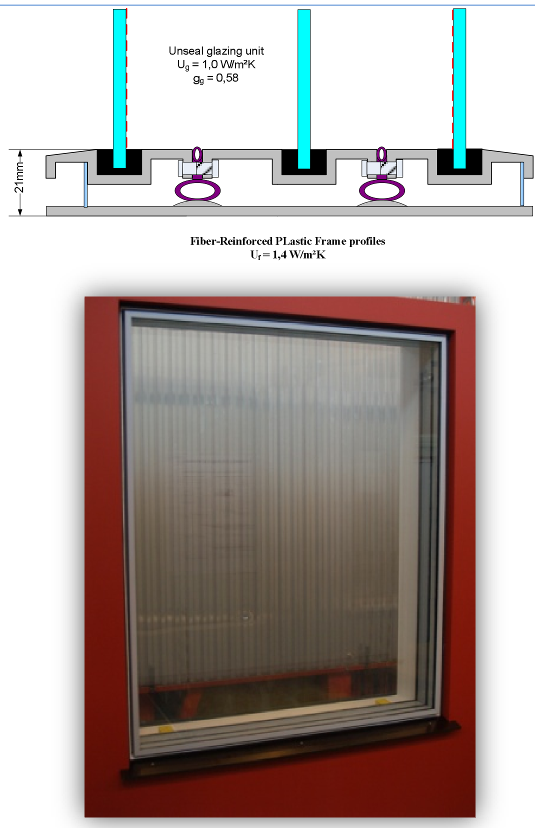



*FIG. 3 The second prototype constructed at DTU*

### 1.3 The performance of today's window products

In figure 4 the performance of different products on the window market 2007/2008 is shown. The net energy gain is presented as a function of the frame width as this is mentioned to be the key for further improvement of the windows performance. This is also indicated by a random selection of certified passive house windows from Germany (http://www.passiv.de). The glazing and frame profiles of the passive house windows have almost the same U-value (0.6 – 0.8 W/m²K). The aim of the project is to improve the performance of the window to a net energy gain above 20 kWh/m² per year (In Denmark).

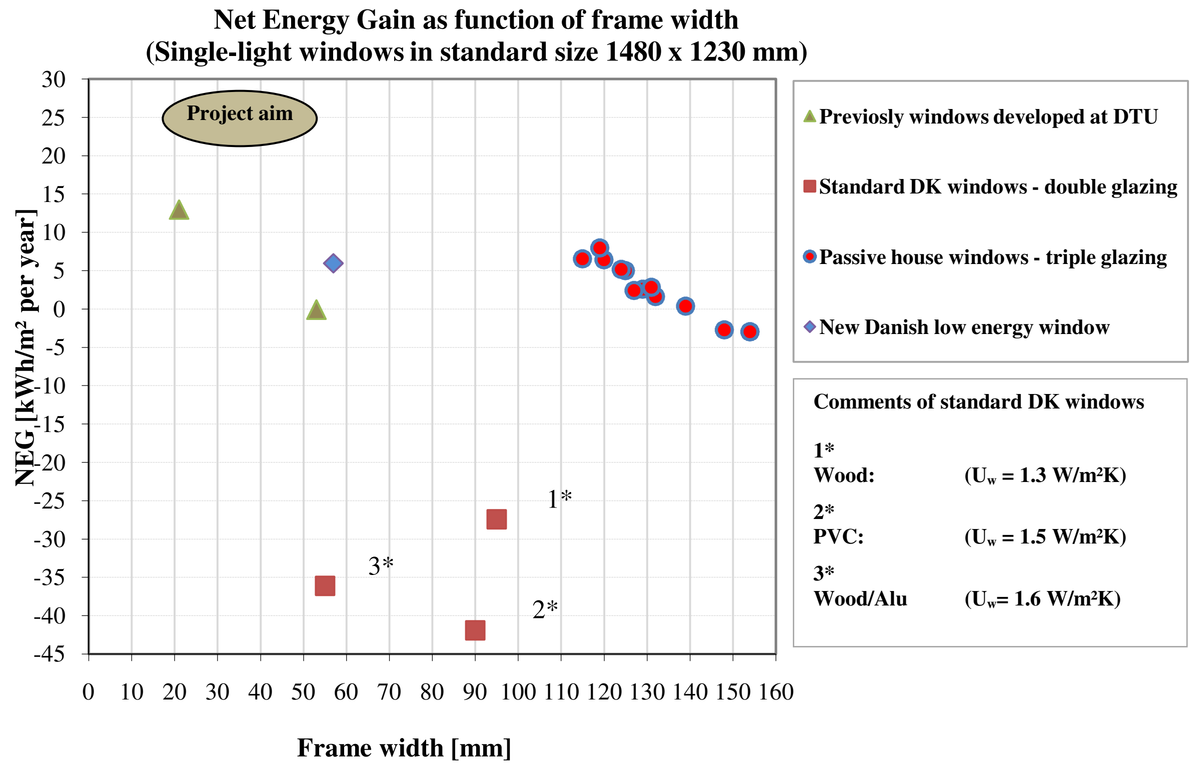



*FIG. 4: Examples of the net energy gain for typical Danish windows of wood, pvc and wood/alu, certified passive house windows from Germany and two windows previously developed at the Technical University of Denmark.*

From figure 4 it is evident that the passive house windows with slim frame profiles perform best regarding the net energy gain. Comparing the Danish standard products of wood, pvc or alu/wood shows a significant difference in the net energy gain.

It also has to be mentioned that in the end of 2007 a new low-energy window was introduced on the market from the Danish company PRO TEC Vinduer A/S. The window's performance is impressing, as shown in figure 4, due to a triple glazing unit with gaps filled with krypton ($U_g$ = 0.52 W/m²K). This is however a little worrying as krypton is more expensive (compared to argon) and thus the price of the window is expected to be relatively high.

## 2. Design proposals for Energy Gaining Windows

In this paper only two of the frame-proposals developed in the project are presented. The main difference to the other proposals of the frame designs is the opening function of the windows. The first presented frame profile is designed for a reversible window and the second is designed for a top or side-hung window.

## 2.1 The optimization method

As the main target is to develop a window that reduces the total consumption for heating of the house the optimization process is divided into separate key points as shown in figure 5.

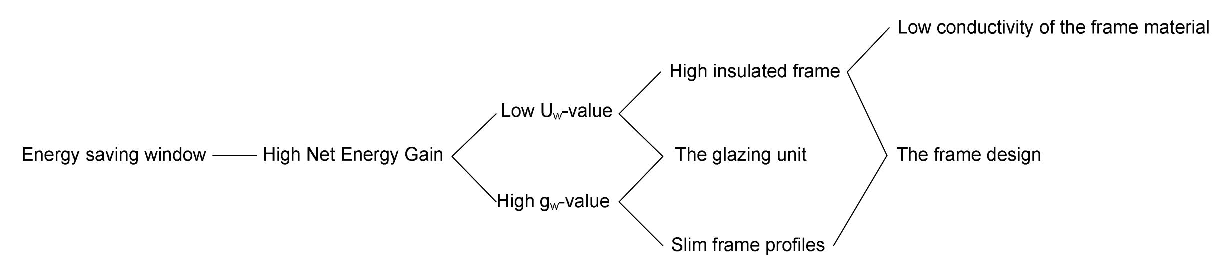



*FIG. 5 The method for optimization of the net energy gain of a window*

## 2.2 Other demands of the window design

In the design phase of the window other aspects also have been considered. These are listed below.

- Fulfilling the different window standards requirements
- Flexible profile system
- Same profile design for top, bottom, and side
- Architectural
- Opening function
- Materials
- Production cost
- Lifetime
- Maintenance

The most influencing and limiting demands when designing slim frame profiles are perhaps the mounting instructions of the glazing unit as shown in figure 6.

**Glazing mounting instructions**
The glazing mounting instructions, elaborated by the Danish glazing organization have to be fulfilled due to the guarantee of the lifetime of the glazing unit. The mounting instruction has specific demands to the frame design ensuring that the glazing unit is both drained and well supported. The figure shows only some of the demands.

(Glasindustrien, 2008)

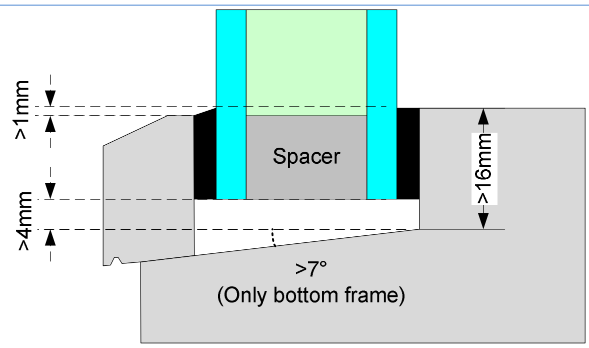



*FIG. 6 The mounting instruction for glazing units elaborated by the Danish glazing organization*

## 2.3 The glazing solution

As mention in the introduction the heat loss from the glazing unit has been reduced significantly during the last 10 years. The standard glazing product on the Danish market 2007/2008 is a double glazing unit with a soft low e-coating and argon fill (4/16Ar/E4). The U-value is 1.1 W/m²K and the g-value is 0.61. The next generation of low-energy glazing in Denmark is probably a triple glazing unit with argon (4E/16/4/16/E4). The U-value of this is 0.62 and the g-value is 0.55 ((http://www.passiv.de). This is also the most applied glazing in German passive house windows. For this project the priority of the glazing unit has also been to use a standard product to keep the extra cost of the low-energy window at a minimum. This glazing unit has therefore been selected as the best solution for the design of the low-energy window.

## 2.4 The frame design proposals

Several research projects have concluded that the method to maximize the Net Energy Gain is a slim frame construction. The project has therefore focused on developing these frame constructions in composite materials. The composite material, fiber glass reinforced polyester, is a complex material that is light, strong and resistant to corrosion, with low thermal conductivity, which makes it extremely suitable for window profiles.

Another issue that also has been a key objective in the developing process was to design a profile system that only consists of one or two different profiles to minimize the production cost.

In figures 7 and 8 the two most promising profile systems developed in the project are presented.

**Design proposal 1**

One of the large challenges making slim frame profiles is to make a reversible window as the hinges for this window type requires relatively large space in the frame. This problem is solved by using a detachable attack list. The idea is that the attack list should be easy to remove and mount without using any kinds of tools. If the owner wants' to reverse the window the attack list is removed in the top and the bottom. Two stainless steel bars supports the frame from the top. The function of the window is also shown in figure 7.

It was also decided to make an alternative assembly of the frame and glazing unit. The standard solution is a detachable glazing bead which makes it possible to replace the glazing unit. This is not possible with the shown proposal as the frame is closed around the glazing unit. If e.g. damages of the glazing occur the idea is that the producer delivers a complete new frame with glazing unit as this is not easily replaced.

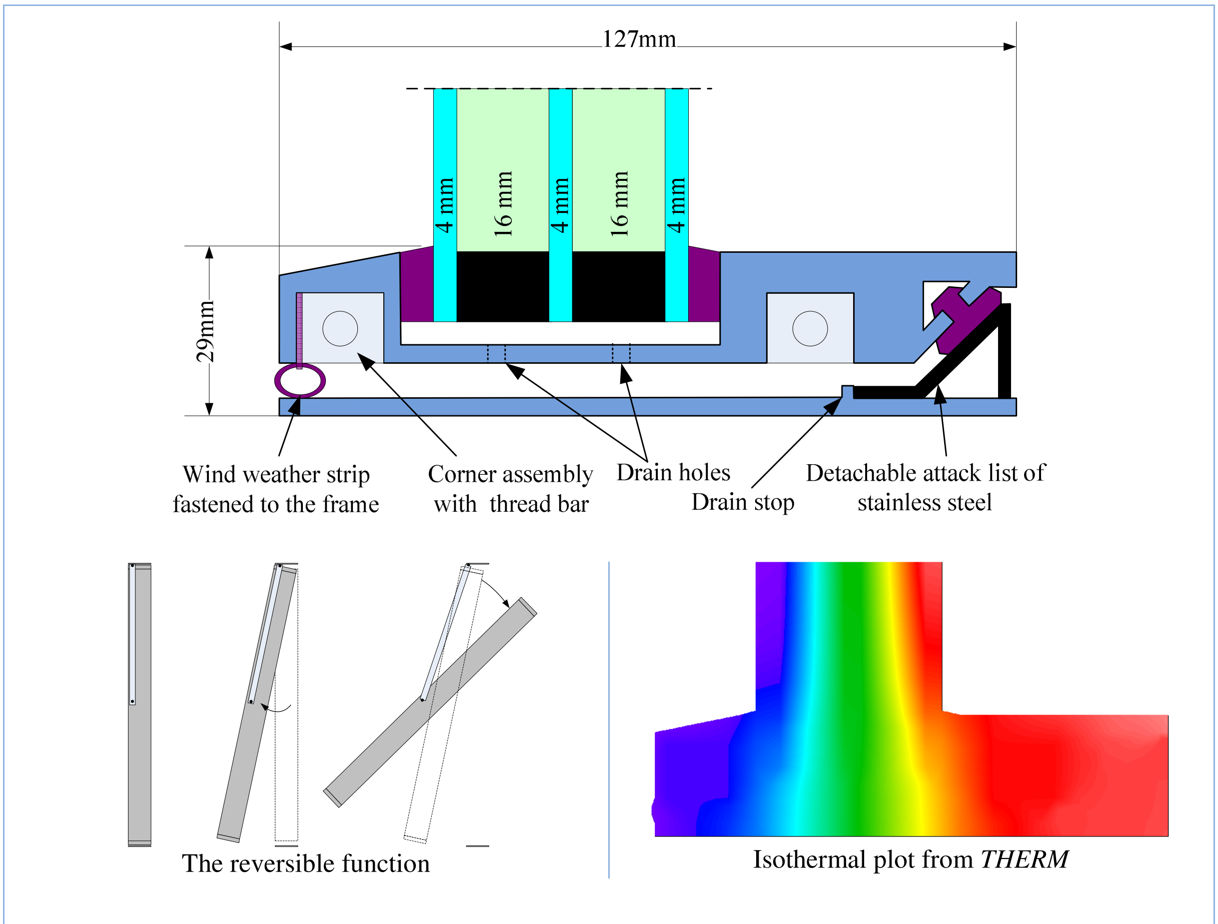
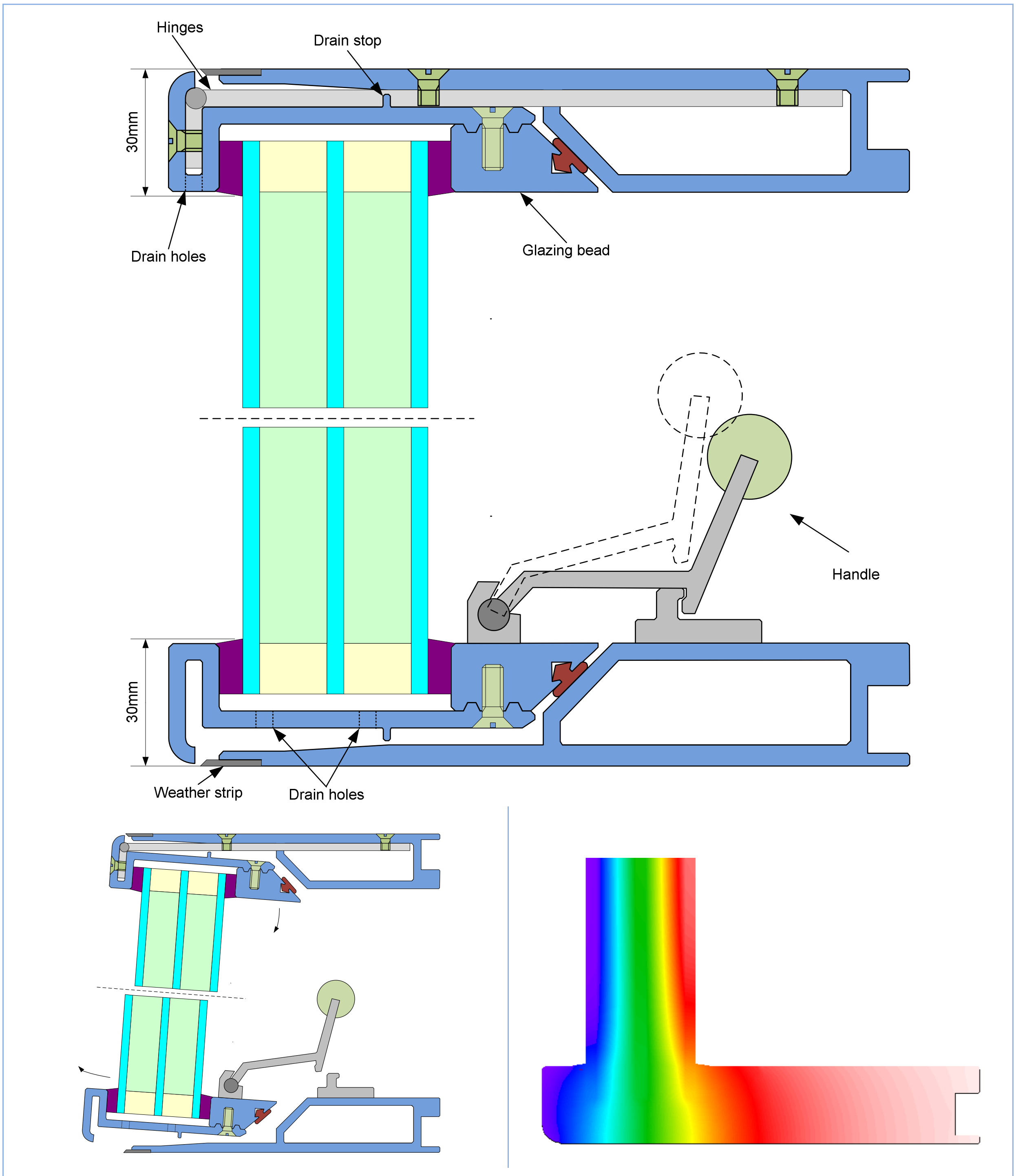



*FIG. 7 Design proposal 1: Slim frame profile for a reversible window using a detachable attack list. In the bottom the turning functions and an isothermal plot of the profile are shown.*

As shown in figure 7 the angle of the bottom cavity below the glazing unit does not fulfil the requirement of an angle of 7° to drain the profile. Instead small draining holes should be made along the profile.

**Design proposal 2**

The second frame proposal is a top or side-hung window. It is with this profile system possible to change the glazing unit by removing the glazing bead.




The opening function Isothermal plot from *THERM*

*FIG. 8 Design proposal 2: A top or side-hung window. In the bottom the opening functions and an isothermal plot of the profile are shown.*

Just as proposal 1 the angle of the bottom cavity below the glazing unit does not fulfil the requirement of an angle of 7° to drain the profile. Instead small draining holes should be made along the profile.

### 2.5 The performance of the two design proposals

The U-value and Ψ-value of the two proposals were calculated according to the standards EN ISO 10077-1 (CEN, 2000) and EN ISO 10077-2 (CEN, 2003). The calculation program *THERM* (LBNL, 2005) was used to simulate the 2-dimensional heat transfer. The performances of the two windows are shown in table 1.

*TABLE. 1: The performance of the presented proposals for improved window with slim frame profiles*

| Proposal | Frame width | $U_f$ | $\Psi_g$ | $U_w$ | $g_w$ | Net Energy Gain |
|---|---|---|---|---|---|---|
| | [mm] | [W/m²K] | [W/mK] | [W/m²K] | [-] | [kWh/m²] |
| Proposal 1 – reversible | 29 | 1.79 | 0.037 | 0.82 | 0.50 | 24 |
| Proposal 2 - top/side-hung | 30 | 1.52 | 0.031 | 0.79 | 0.50 | 28 |

Compared to Danish standard windows the energy saved for a house with 20 m² of windows could easily larger than 1.000 kWh per year.

## 3. Conclusions

Two proposals for slim frame profiles have been developed and designed at the Technical University of Denmark in a new project. The proposals have improved the Net Energy Gain of the windows significantly even compared with certified passive house windows. The net energy gains of the windows are positive and the windows are hereby not an energy consuming construction of a house but an energy gaining construction.

Both proposals use a triple glazing unit (4E/16Ar/4/16ArE4) as this is expected to be the standard solution of a low-energy glazing in the future.

The first proposal is a reversible window type with a detachable attached list, which must be removed before turning the window. The width of the frame was reduced to only 29 mm. The $U_f$-value and Ψ-value of the frame profile are calculated to be 1.79 W/m²K and 0.037 W/mK, respectively, and the net energy gain is then calculated to be 24 kWh/m². The second proposal is a top or side-hung window. The width of the frame was reduced to only 30 mm. The $U_f$-value and Ψ-value of the frame profile are calculated to be 1.52 W/m²K and 0.031 W/mK, respectively, and the net energy gain is calculated to be 28 kWh/m². The aim of the projects is thereby fulfilled.

## 4. Acknowledgements

This work was financed by the Danish Energy Authority, Energy Research Programme (ERP).

## 5. Future work

The presented proposals have to be described and analyzed in details. Also the strength and possible weaknesses should be analyzed further. The best suitable hinges and handles should be found by investigating the market. Finally, prototypes of the most promising windows should be constructed for test in the laboratory.

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